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DESIGN AND PROTOTYPING OF A FLEXIBLE PREFABRICATED MODULE FOR LOFT CONVERSIONS. THE "MADE IN ITALY" NATIONAL RESEARCH PROGRAMME.

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Abstract *In order to cope with the modern environmental, economic and social issues, urban densification appears as one of the possible solutions to limit land consumption, infrastructure and transport costs, to increase quality of life and to promote a more efficient use of energy in metropolitan areas. Since ancient times the addition of new volumes to the existing building has been adopted as an ordinary practice to respond to the changing needs of the inhabitants. Today rooftop architecture can be used to intensify the existing metropolitan areas, inject them with new vitality and diversify the mono-functionality of a neighbourhood. Besides, it represents an opportunity for the energy upgrading of the built environment since the exploitation of rooftop space as open available area where to erect new structures not only allows for land consumption control but also it often entails the requalification of the roofing construction. Moreover the addition of new inhabitable spaces can be part of a governmental or municipal energy incentive policy to trigger private initiatives towards refurbishment and requalification projects aimed at improving the overall energy efficiency of the 'supporting' existing buildings. This paper describes the results of an ongoing multidisciplinary government funded research project focusing on the development and prototyping of an energy efficient flexible and adaptable modular prefabricated system for residential rooftop additions exploiting Xlam laminated timber panels. In particular this work presents the meta-design concept of the prefabricated system as the final outcome of a specific methodological process which through preliminary targets definition, users requirements assessment and the exploration and evaluation of different techno-typological solutions has been conceived in order to provide the maximum adaptability and spatial and combination flexibility as well as the highest energy efficiency (passive and active systems) to the modules.*

1. INTRODUCTION

Continuing population growth and urbanization prospects which are expected to add 2.5 billion people to the world's urban population by 2050 [1] and the rapid expansion of emerging economies pose serious challenges to control human activities impacts on the planet and require a general rethinking of urban development approaches. Cities densification is considered [2] as a possible solution to limit land consumption, infrastructure and transport costs, to increase quality of life and to promote a more efficient use of energy in metropolitan areas.

Although the possibilities to use more densely the space in big cities are limited, the stacking of functions or the putting of industrial premises to new uses are potential strategies. Moreover the use of flat roofs of residential buildings and office blocks as building sites, namely rooftop architecture, can intensify the existing metropolitan areas, inject them with new vitality and diversify the mono-functionality of a neighbourhood [3].

These addition spaces set upon existing architectures, through temporary or permanent projects, cause a global change that takes part in urban requalification and recalls the idea of Buzz Design, i.e. that swarm of medium to small projects, as defined by A. Branzi [4], which create a new expressive and cultural level of the urban environment. "In Architecture almost all the buildings are subjected, from the time of their completion, to viral aggregation phenomena which transform them. The elimination of some parts; the addition of other, the superfetation of volumes which parasitize the original ones; the change of the construction materials constitute a constructive affair which is also, as a whole, a demonstration of extreme vitality" [5].

Historically, in times of crisis, we observe a contraction in the building sector which leads to a development of intensive exploitation of existing architectures. Raising the height of buildings has become once again a big trend in the last years, in connection with another main current issue: environmental sustainability. In fact the exploitation of rooftop space for new buildings not only allows for land consumption control - over the last five years, 100.000 sqm of new housing surface have been created, in Milan alone, saving a great amount of agricultural and non-urbanized areas- but also entails, in the majority of cases, the requalification of the roofing construction, therefore increasing the energy efficiency of the built environment.

In this context and within the general "Progetto INDUSTRIA 2015" research - funded by the Italian Ministry of Economic Development - a new proposal was launched related to the objective area "Markets Strategic Protection".

The "Rooftop XLam MadeinItaly" research project, started in 2011, has in fact the goal of creating a promoting and selling centre to showcase an innovative self-sufficient modular prototype for rooftop architecture using Xlam laminated timber panels. The design of the new prefabricated dwelling unit addresses international markets and involves multidisciplinary competences and diverse institutions and authorities (Distretto Tecnologico Trentino (Habitech), CNR-IVALSA, GREEN BUILDING COUNCIL ITALIA, Politecnico di Milano (Department of Design) and Università di Trento), together with private enterprises,

manufacturers, architectural firms and engineering societies.

The aim of this paper is to illustrate the development of the project, which is currently in progress, through the implementation of specific methodologies and eventually to draw possible paths for the scaling up of the initiative.

2. METHODOLOGY

The complex structure of the overall methodology of the research responds to the large and manifold number of the participants involved and to the complexity of the project, to be carried out from the concept to prototyping, though maintaining a flexibility of application to different sites.

Following a project management approach, an accurate and detailed work-plan was prepared, compiled with the consecutive steps - from state of the art analysis to concept definition, development of the design, detailing and construction, to results evaluation - split up in specific activities, each attributed over a scheduled time to each of the collaborating participants.

The present paper focuses on the specific input of the Politecnico di Milano participants though making references to the results of the other research groups, all together involved in a cooperative teamwork. In particular, the Politecnico di Milano team was assigned roles in the preliminary survey and in the concept development.

The first task was carried out through the collection of a large number of case studies of rooftop construction in Europe and all over the world with the double aim of understanding the architectural and compositional relationship between the existing building and the new rooftop and of defining the potential targets.

A specific data sheet model was created to organize the information gathered on each case study and highlight and compare selected features and characteristics. Accordingly different categories were introduced to propose a possible taxonomy of the rooftop architecture phenomenon portrayed by more than 30 outstanding examples.

Therefore, together with the aid of the overall problem setting phase, the development of the concept was performed through a multidisciplinary teamwork and an iterative creative cyclic process of improvement.

3. DESIGN OF THE PREFABRICATED MODULE

3.1. Stylistic approach and target definition

Since one of the main objectives of the prefabricated unit is its flexibility of application in different European countries, a thorough initial investigation was carried out in order to identify a range of possible solutions to structure the framework of the following project development phase.

Not only modularity and prefabrication, structural systems and assembly, building services, construction logistics, regulation constraints were examined, but also aspects concerning architectural composition, outstanding design, space organization and relationship between

the new volumes and the existing building. These latter analyses, entrusted to the Politecnico di Milano team, were carried out through the identification and interpretation of contemporary rooftop architecture examples.

The first result of this investigation was to determine whether the new addition should be conceived to mimic the same style of the existing building or to adopt a different own language. Stylistic discontinuity though seemed the more appropriate choice not only because of its frequency in the most successful case studies analysed, but also for the project purposes to extensively respond to flexibility requirements and to be easily recognizable and identifiable as an outstanding specimen for the branding of the Made in Italy approach. One of the earliest contemporary demonstrations of stacking an extraneous element on the existing architecture dates back to the early 80's and was designed by Coop-Himmelb(l)au in Vienna. It proved that a wise use of innovative modern technologies, along with a formal research detached from the existing historic language, enables a dialogue and interaction between the two volumes without stylistic mimicry. This became the manifesto of the cultural approach to the project.

Secondly, the state of the art investigation and evaluation allowed for the pinpointing of the following six macro categories [7] representing potential targets for the project.

- The roof as new land. This category encompasses cases introducing a semantic detachment between the stacked functions. The existing flat roof surface is used as a real new high level area to build on and where to add both open and enclosed spaces.
- Landmark. The rooftop architecture acquires symbolic meaning to communicate new values and introduces a new significance to the construction below or to the neighbouring urban area.
- Living in a box. The category comprehends extensions, usually residential, occupying just a minimum roof area prompted by the need to enlarge an existing housing unit, even by one room only. These projects are often made of self-building or high-standard prefabricated systems.
- Temporary. This represents the most transversal trend embracing different functions and involving special, easy to dismantle or easy to transport technologies.
- Seriality. The rooftop addition can offer the opportunity for the construction of a new settlement, comprehending a series of dwelling units often entailing the refurbishment of the existing building.
- Green. The new construction focuses on energy efficiency both of the new and of the hosting volume, even adding systems for renewable energy production.

All the targets identified were useful for the potential demand analysis to guide the concept development.

3.2. Concept development

As a result of the general first step analysis and framework definition some specific features and requirements of the rooftop addition were outlined.

The prefabrication system should produce 3D modules to be just transported and placed on the roof, not parts and components to be assembled on site. This choice allows to reduce time of construction and to limit as much as possible local labour, in order to control the final quality of the product and to emphasize the made in Italy know-how. Consequently the dimensions and weight of the prefabricated module should comply with the truckload transportation rules. Moreover the compositional flexibility of the project relies on the multi-functionality of the single module and on the variety of units' combination.

Issues concerning physical (structure, services, accessibility) relationship with the existing building, together with the energy self-sufficiency goal, were faced through the plinth and roofing intermediate solutions. The modules in fact will stand on an elevated platform about 50 cm above the existing flat surface to distribute the additional loads on the loadbearing roof structure. The platform can be extended beyond the perimeter of the modules to add external terraces and open spaces to the dwelling unit. Presuming the accessibility to the roof surface through an existing staircase/lift, the platform can be shaped to introduce steps or ramps to reach the floor level of the new house.

Furthermore the created cavity - a sort of crawl space - can host the new building services, allowing for an easier accessibility and maintainability of the systems and for a high spatial flexibility over time. This choice can also tackle with the problem of the connection with the existing grids having a diverse and unpredictable position according to the different sites.

The double roof solution adopted responds to specific requirements and offers different benefits. First it is a typology with a higher energy performance especially in hot climates, since the upper cover works as a sun shading device, allowing cross ventilation underneath and protecting the lower surface from weathering, with an increased durability as a major result.

Secondly, the upper pitched cover can be adapted to different geographical contexts, adopting the more suitable inclination to support photovoltaic and thermal solar panels. This solar canopy, to be extended, if needed, beyond the prefabricated units to protect the platform terraces and open spaces, can respond to energy demands not only of the new housing but possibly of the existing building below. Moreover both the double roof and the platform solutions can contribute to increase the compositional flexibility of the prefabricated system and the relationship modalities with the supporting building.

The spatial definition and organisation of the modules together with the combination and aggregation systems were conceived since the early starts taking into account dwelling dimensional standards and fruition requirements as well as structure and building services issues.

The Xlam Cross Laminated Timber, in fact, is a structural two-way spanning timber panel that can be used to form walls, roof and floor panels as well as shear walls. Accordingly, space planning has to consider the constraints of the main linear loadbearing vertical panels to support the horizontal structure together with perpendicular shear walls, also having the modules to respond to seismic design requirements. The Xlam structural system has a particularly high performance in resisting to vertical and horizontal earthquake loads [8], though presenting some constraints which might limit design freedom. For instance, external

openings width as well as rooms' extension can be possibly limited, also because, modules have to be trucked and therefore comply with predetermined maximum bulk dimensions.

However, in order to have a continuity of the internal spaces, and to avoid the presence of loadbearing vertical elements, the posts of the Xlam portals to build the main linear structure of the modules have been "concealed" within the module transversal walls which become thick cavity wall systems to contain the accessible vertical distribution of the building services as well as integrated furniture such as closets, shelves, movable desks, etc., to almost completely fit out all the rooms. Hence a further degree of spatial flexibility is provided, introducing an added value to the concept and suggesting a different usability of space and innovative adjustable tools to respond to modern quickly changing lifestyles

The metadesign proposal has been organised adopting a regular square grid (240 x 240 cm) to guide the project both for the arrangement of the vertical supports and to accommodate the intended patterns and scale of activities.

The concept, focusing on flexibility enhancement, developed a unit with a multifunctional character and with a diverse range of available combinations to cope with the varied targets previously defined.

The basic 240 x 720 cm module (3 squares of the grid) consists of a rectangular bay with Xlam loadbearing longitudinal panels on the sides, actually two portals, presenting the largest openings admissible (about 300 cm wide). The combination of two of these modules allows the creation of a larger room with the addition of two parallel ancillary smaller spaces separated in between by the intermediate laminated loadbearing timber panel. The two transversal opposite sides are dedicated to wall units as integrated furniture and as chases for the vertical distribution of building services. In case, according to the structural design, shear walls or openings can be created in this area. The two modules combination can accommodate either the sleeping or the living area of the house. In the first case the double bedroom is completed with a bathroom and a closet, in the second case the living/dining room is equipped with a kitchenette and an entrance/storeroom. The combination of these four modules (ca 69 sqm of gross floor area) is suitable for a two people apartment, whereas the addition of a further module to the dining room, enlarging the living area and introducing a further toilet, together with the juxtaposition of another three squares module as a single bedroom can accommodate up to three people (ca 104 sqm of gross floor area). The combination of the different units can in fact encompass additions following both longitudinal and transversal directions and according to a parallel serial proximity or staggering the volumes. In any case a continuity and adjacency of the ancillary spaces is considered as a rule, to exploit the continuous cavity within the suspended ceiling for the horizontal distribution of the mechanical services.

Thus the diverse combination of the units, can flexibly respond to different quantitative requirements of one single room - suitable to the Living in a box target, pinpointed in the first stage of the research - of a flat for two, three, four, up to six people and more or a cluster of apartments, to tackle instead with the Seriality target.

A further customization can be introduced with the façade external cladding system (a palette still under development) or with the introduction of greenhouse modules to enhance the

energy performance of the rooftop construction especially in Northern European contexts.

All the construction is conceived with dry assembly systems to increase the overall ecological performance of the project with recyclability and reuse.

4. CONCLUSION

Supplementary development of the project include the definition of the façades cladding and the choice of interior finish to improve the quality of the proposal with a suitable selection of materials. The definition of a possible catalogue of solution together with the spatial flexibility of the system, actually result in the design of a prefabricated dwelling system to respond to a wide range of housing demand beyond rooftop architecture and with different targets

In fact another potential for the scaling up of the project can be supplied by the enlargement of the geographical and social context of prospective application of the prefabricated system. Volumetric incentives offered by the upcoming new local regulation in Milan to reward the energy upgrading of existing building can represent a further opportunity for the project implementation. Finally the growing demand for social housing indicates a possible development of the proposal to be added on the rooftop of existing public housing estates controlling costs through finishes and materials selection., as already experimented for instance in proposals such as the Requalification of Public Housing estate in via Russoli, Milan, by Mario Cucinella Architects, 2009; or in the Rooftop construction on a public housing estate by Studio Albori in Cinisello Balsamo (Milan), 2004 – 2007.

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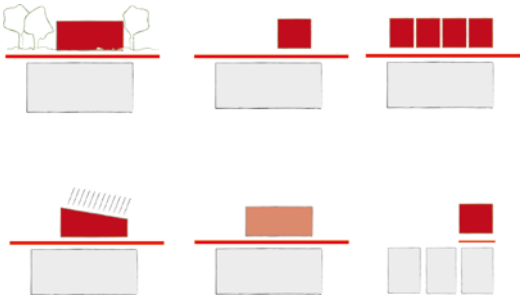

Figure 1 The six macro categories representing potential targets for the project. From top right side: The roof as new land, Living in a box, Seriality, Green, Temporary, Landmark

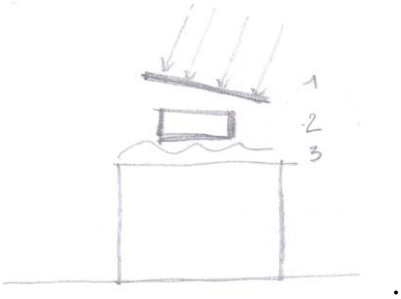

Figure 2. The modules (2) will stand on an elevated platform (3) above the existing flat and adopt a double roof solution (1).

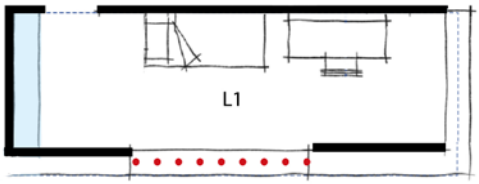

Figure 3. The basic 240x 720 cm module.

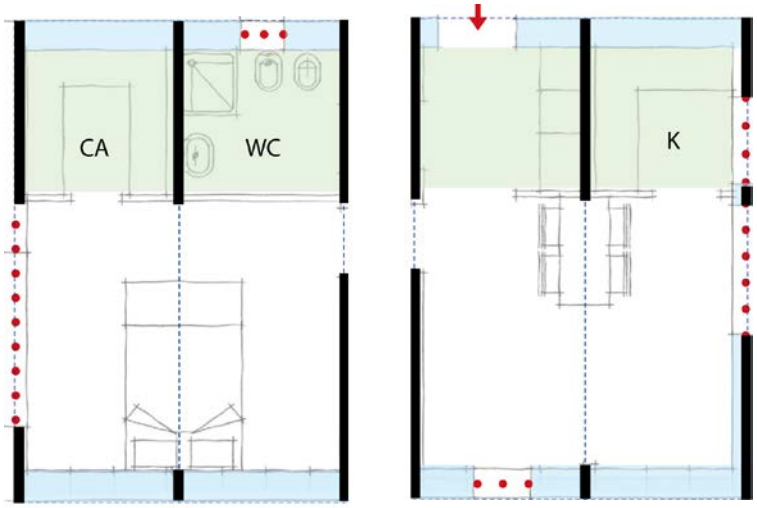

Figure 4. The two modules combination can accommodate either the sleeping or the living area of the house. In the first case the double bedroom is completed with a bathroom and a closet, in the second case the living/dining room is equipped with a kitchenette and an entrance/storeroom.

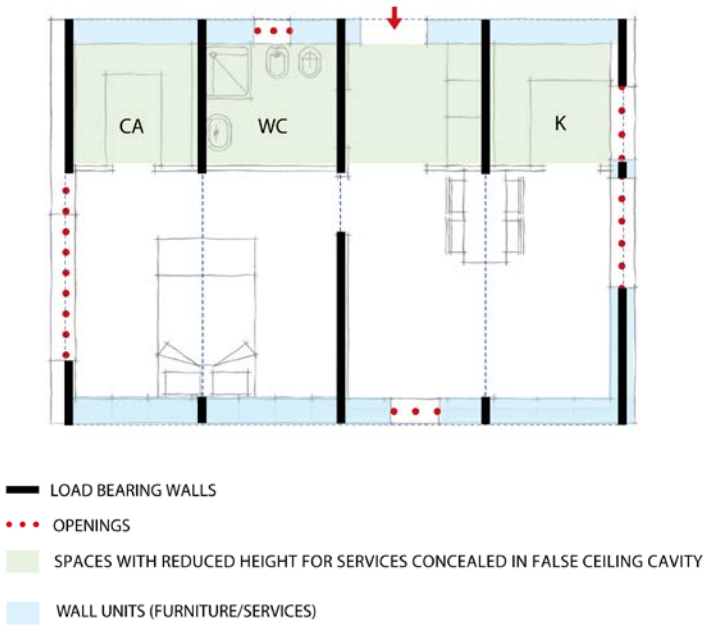

Figure 5. Hypothesis (A) modules combined in parallel with continuous linear services band hypothesis.

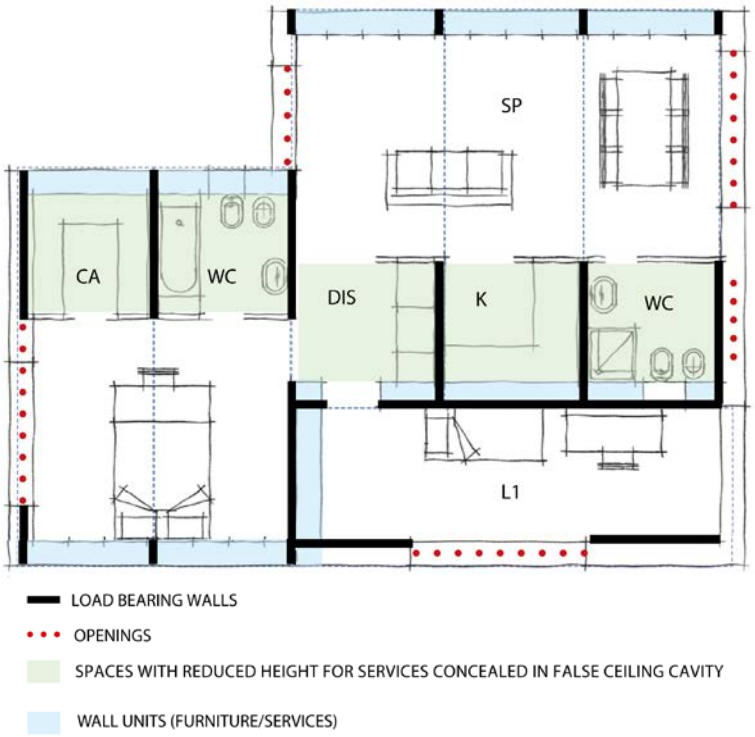

Figure 6. Hypothesis (B) modules combined longitudinally and transversely opposite but staggered to provide continuity to the spaces with reduced height for services concealed in false ceiling cavity.